Things of science

SEXTANT

Unit No. 234

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In this unit of THINGS of science you will find the materials necessary to construct a sextant with which you may "shoot the sun and the stars."

First, identify the materials included in this unit.

SEXTANT DIAGRAM -- Cutouts to be pasted on heavy backing to form the sextant.
POLYETHYLENE VIAL -- To be used as a level in the sextant.
MIRROR -- Completely silvered, the index mirror.
HALF MIRROR -- The horizon mirror.
SNAP FASTENER -- Pivot for the index arm.
SHADE PAPER -- Colored cellophane to be used to protect your eyes from the direct rays of the sun.
BLACK PAPER -- To form sighting tube.

In order to find one's position at sea with no landmarks to give you a clue as to your whereabouts, it is necessary to determine the altitude of a celestial body. To obtain this accurately the observer must see both the horizon and the sun or star simultaneously. At the beginning of the 18th century a reflecting instrument was produced that was called a sextant because its graduated arc is one-sixth of a circle.

The construction of the sextant is based upon two principles, the first of which is that the angle of incidence is equal to the angle of reflection. The angle of incidence is the angle that is formed by a line perpendicular to the mirror and the path that a beam of light travels to strike the mirror. The angle of reflection is formed by the reflected ray and the line perpendicular to the mirror.

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Experiment 1 -- On the diagram of the completed sextant, draw a dotted line, CI, so that it bisects the angle SIH and is perpendicular to the index mirror. Then extend this line a short way beyond I. Extend SI with a dotted line from I to E, where the eye is placed. Now draw a third dotted line perpendicular to the half mirror. This line will bisect the angle IHE. Where this line cuts the extended part of the dotted line CI behind the index mirror, mark the point D. Since the angle of incidence is equal to the angle of reflection: SIC = CIH and IHD = DHE.

The second optical principle upon which reflecting instruments are based is that "the angle between the first and the last direction of a light ray which has undergone two reflections in the same plane is twice the angle of inclination between the two mirrors."

Experiment 2 -- With the aid of the first principle and geometry we can prove the truth of the second principle which is the fundamental principle of reflecting instruments.

First you must insert a piece of paper beneath the drawing that extends at least four inches beyond the lower part of the drawing. Attach the paper to the sextant drawing with transparent tape. Now draw a line parallel to the index mirror along the index arm until it is about four inches long. Draw another line from the half mirror parallel to it, until this line intersects the line drawn from the index mirror. Label the point at which they intersect P.

The first principle showed us that: SIC = CIH and IHD = DHE. Therefore, SIH = 2CIH and IHE = 2IHD.

Since the exterior complementary angle of a triangle is equal to the sum of the two opposite angles, in triangle IHE: angle SIH = IHE + HEI. It follows that: HEI = SIH - IHE.

As you can see angle HEI is the same as AES, therefore you may substitute: AES = 2CIH - 2IHD. But in triangle IHD, CIH - IHD = IDH. Substituting: AES = 2IDH. Since their sides

are respectively perpendicular, angle IDH = IPH. Therefore, AES = 2IPH.

AES is the angle of altitude of the celestial body and IPH is the measure of the angle of inclination of the planes of the reflecting mirrors. Therefore, the angle of altitude of a celestial body is twice the angle of inclination made by the planes of the reflecting mirrors.

CONSTRUCTING THE SEXTANT

Now that you understand the principles of the sextant, look carefully at your sextant cutouts. The diagram consists of the base of the instrument containing the graduated arc, to which is attached the index arm which holds the index mirror, the level holder sights and the horizon, or half, mirror.

Experiment 3 -- Find some heavy cardboard, plastic sheeting, thin wood or metal to use as a backing for your sextant. The more rigid the material the more useful and accurate your instrument will be. Cut out the base of the sextant. Attach the base to your backing material which has been cut to the same shape.

Using pattern C, cut from your backing an identical figure. Increase the diameter of the sights to one-quarter inch using the circle marked on the pattern as the exact center for your larger circle. Fold the sights and level holder as marked on the pattern and paste down on the base to match exactly C'. Insert the polyethylene vial in the holes marked for the level. Roll the black paper included in this unit into a tube and insert through the holes marked for the sights to give you a sighting tube for your sextant.

The handles of the sextant are in the middle of the base and should be cut along the solid lines. When you have completed the construction of the sextant, fold the handles back along the dotted lines, which will give you a firm hold for the sextant. If you prefer, punch holes at the crosses indicated within the handles

and insert rubber bands to use as handles if you do not wish to weaken your sextant base by cutting out the handles.

Cut out the mirror holder marked A. Cut from your backing material an identical figure and paste the pattern to the backing. Now cement your mirror holder to match A' .

You must match exactly the area between the two upright pieces on the mirror holder with the parallel lines that extend beyond the rectangle A' . Place the half silvered mirror in the holder. The mirror must be at right angles to the base of the sextant.

The index arm is found to the left of the sextant base on the sextant drawing. Cut out along the heavy black lines. Cut out mirror holder B and paste down on B' . Be sure the areas between the two upright pieces are identical with the parallel lines on the circle of the index arm.

Examine your snap fastener carefully; you will find that the depression on one part contains two pieces of wire and the surface of the fastener is slightly curved. The other component of the fastener has a flat base and a longer hollow knob which fits into the depression containing the two wires. The snap fastener is used to attach the index arm to the base of the sextant, so that the index arm may be rotated freely. The placement of your snap fastener components to a large extent will determine the accuracy of your instrument.

Experiment 4 -- With a pin punch a hole in the middle of the circle on the sextant base which is the pivot point for the index arm. Using the snap fastener with the two wires in the depression, attach the fastener to the sextant base with household cement so that the two wires of the fastener show. Precision is easy if you insert a pin through the small hole in the depression in the fastener, and then push the pin into the hole in the sextant base. Be sure that the index arm circle is centered with the

circle on the sextant base. Now force the pin from the sextant base through the exact center of the circle of the index arm. Using a pin to center the flat-based snap fastener, attach it to the index arm so that it will fit into the other half of the snap fastener. When your cement has dried, join the fastener parts together and rotate the index arm.

Experiment 5 -- Remove the level from the level holder and fill the vial with water and add a small quantity of detergent powder. Leave just enough air at the top of the vial so that when you tip the vial on its side you have a small bubble. Can you hold the bottle so that the bubble remains in the middle? When the bubble is in the center the vial is level. When you tip the vial, even slightly, the bubble leaves the center of the vial. With this bubble to indicate when your sextant is level, you can use your sextant on land as well as at sea. Now place the polyethylene vial in your level holder.

Except for the placement of the index on the lower portion of the index arm your sextant is now complete. Check the drawing of the sextant to see that your model is put together correctly.

The sextant as it is used for navigation is a precision-built instrument. The sextant model which you have constructed from this unit of THINGS of science will give you an understanding of the operation of the sextant. This model is based upon a sextant which was designed by Joseph H. Kraus, Coordinator of the National Science Fair. Appreciation is expressed to Mr. Kraus for his help in the preparation of this unit.

In order to make your sextant as accurate as possible, there are several points that should be checked.

Experiment 6 -- To determine whether the index mirror is perpendicular to the plane of the graduated arc, rotate the index arm to about the center of the graduated arc and hold the sextant horizontally so that the eye is in the plane of the graduated arc and near the index mirror. Look into the index mirror and

notice whether the image of the arc and the arc itself are continuous. If the two images are continuous, the index mirror is perpendicular to the plane of the graduated arc and no adjustments are necessary. If the reflected image appears to droop away from the direct image, the mirror is not perpendicular, but leans backward. If the reflected image appears to rise, the mirror leans forward. If necessary, adjust the index mirror.

Experiment 7 -- When the index mirror is perpendicular to the plane of the graduated arc, you must now test to find out if, by moving the index arm, the index mirror can be placed in some one position so that it will be parallel to the horizon mirror. If such a position is found, both mirrors are perpendicular to the plane of the graduated arc. This may be tested in the following manner. Hold the sextant vertically in your right hand and look to see that it is level by checking the position of the bubble. It must be in the center of the vial for the sextant to be level. Carefully bring the sextant to your eye keeping it level. Look through the sighting tube and you will see a part of the silvered portion of the mirror as well as the unsilvered portion. Sight an object at least thirty feet away through the unsilvered portion of the mirror. Now move the index arm until the reflected image of the object is also seen. If the reflected image of the object passes over the direct image, the mirrors are parallel and the horizon mirror is perpendicular to the plane of the graduated arc. If the reflected image of the object does not pass exactly over the direct image, adjust your horizon mirror until the reflected image of the object passes exactly over the direct image.

Experiment 8 -- Now that you know both mirrors are parallel to each other and are perpendicular to the plane of the graduated arc, you can paste the index on the lower part of the the index arm. First, choose an object at least thirty feet away and direct your line of sight at this object; move the index arm until the reflected image passes exactly over the direct image. Hold the index arm securely and mark on the lower part of the

arm the zero point from the graduated arc. Choose several different objects and repeat the experiment. Does the zero point remain the same? If so, cut from the sextant drawing the index and paste it on the lower part of the index arm at the point that you have found by experimentation coincides with zero on the graduated arc. When the index arm is in this position the horizon mirror is parallel to the index mirror and the angle of inclination between the two mirrors is zero.

When the index arm is rotated 0.5 degree toward the horizon mirror, the angle of inclination of the two mirrors is 0.5 degree. Since the angle of altitude of the celestial body above the horizon is twice the angle of inclination of the mirrors, this point where the index rests on the graduated arc is designated 1 degree. Thus, by making the graduated arc for any position of the index read, not the angle of inclination of the planes of the two mirrors, but twice the angle, the reading of the graduated arc gives the reading of the altitude.

Experiment 9 -- The most important use of the sextant is in observing the altitude of the sun (its angular elevation above the horizon) for determining the observer's position at sea. Face toward the sun so the part of the horizon in the field of view is directly under the sun. Place the shade paper over the horizon glass to protect your eyes from the direct rays of the sun. Sight the horizon through the clear portion of the horizon mirror. Now rotate the index arm until the glare of the sun begins to reflect into your eyes. Even with the shade look directly at the sun through the sextant only long enough to get a reading. Since this sextant contains no telescope, the horizon is set opposite the middle of the sun's disk, thereby measuring the altitude of the center of the sun, which is required for determination of position.

In observing the altitude of the sun great care should be

taken to hold the instrument vertical when the final reading is taken. The tilt of the instrument may be tested by rotating it about the horizontal line through the sighting tube and the clear portion of the horizon mirror. Hold firmly the index arm and rotate the instrument first to the right and then to the left; the sun will appear to move away from the horizon as the instrument is tilted. The sextant should be swung back and forth and the index arm adjusted so that the horizon is even with the sun's center at the lowest part of the arc. Now read your graduated arc for the altitude of the sun and record this and the exact time. Several observations should be made and the time of each recorded.

Experiment 10 -- Since it is not always possible to see the horizon, the THINGS sextant is a bubble sextant that contains an artificial horizon. The bubble is used to indicate that your instrument is level. To measure the sun's altitude on land, ask a friend to watch the artificial horizon on your sextant to see that you keep the sextant level. Sight through your sighting tube and hold the sextant steady as you bring the reflected image of the sun into view by rotating the index arm.

Experiment 11 -- In observing the altitude of a star, hold the index arm at zero on the graduated arc and sight the direct image of the star through the horizon glass. The reflected image will be seen on the horizon mirror. Gradually lower the sextant and, at the same time, rotate the index arm outward so that the horizon mirror is always visible to you and the reflected image of the star appears in the mirror. Continue these movements until the sextant is perfectly level, as indicated by the bubble. Now take the reading of the star's altitude. Make several observations, recording the time each time you make an observation.

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